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EVALUATION OF THE POSSIBILITY OF OBSERVING NORMAL BEHAVIOR OF AN ORGANISM AT A DEEP SEA HYDROTHERMAL VENT

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Evaluation of the possibility of observing normal behavior of an organism at a deep sea hydrothermal vent

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Suppose an organism is found in viable condition at a certain distance from a vent whose orifice temperature is 400°C, and suppose that same organism is also found at a vent of temperature of 350°C. Assume that in the course of "normal" activity, this organism is exposed, if not continuously at least periodically to the full spectrum of thermal radiation from these vents. It is of interest to calculate the ratio of exposure at 400°C to that at 350°C.

The thermal radiation emitted by a hot body (vent plume into sea water) in the wavelength interval between λ and $\lambda + d\lambda$,

$$n(\lambda)d\lambda = \epsilon \cdot \frac{cn^2}{\lambda^4}\left[e\,\frac{hc}{\lambda kT} - 1\right]^{-1} d\lambda \qquad (1)$$

where ϵ = emissivity of plume

c = velocity of light

h = Planck's constant

k = Boltamann's constant

n = index of refraction of sea water

T = absolute temperature

$n(\lambda)d\lambda$ is in m^{-2} sec-1 per unit solid angle and λ is in meters.

Expressed in more convenient terms with area in cm^2, wavelength in micrometers, taking $n = 1.325$, the expression becomes

$$n(\lambda)d\lambda = \epsilon\,\frac{527 \times 10^{22}}{\lambda^4}\left[e\,\frac{1.44 \times 10^4}{\lambda T} - 1\right]^{-1} d\lambda \qquad (2)$$

Anticipating the applications of ALISS[1 to the proposed observations, noting the quantum efficiency of the CCD employed, as shown in Figure 1 and the attenuation of sea water as shown in Figure 2, consider the wavelength interval 800 ± 50 mm. The number of photons emitted cm^{-2} sec^{-1} into unit solid angle at temperature T is:

$$N = \epsilon \cdot 1.3 \times 10^{22} \left[e \; \frac{1.8 \times 10^4}{T} \; - 1 \right]^{-1}$$

At temperature 350°C (623°K) this is

$$N = \epsilon \cdot 1.3 \times 10^{22} \left[\epsilon^{28.8} \; - 1 \right]^{-1} \quad (3)$$
$$= 4.0 \; \epsilon \times 10^9 \text{ photons } \mathrm{sec^{-1} sr^{-1} cm^{-2}}$$

For $\epsilon = 0.3^{(2}$, $N = 1.2 \times 10^9$ photons cm^{-2} sec^{-1} sr^{-1}. Now consider the temperatures at which 2x, 5x this radiation is emitted i.e.,

$$\frac{N_T}{N_{350}} = \frac{\epsilon^{28.8}}{\epsilon^{\frac{1.8 \times 10^4}{T}}} = 2 \text{ or } 5$$

For ratio of 2: $\ln 2 = - \frac{1.8 \times 10^4}{T} + 28.9 = .69$

$T = 638°$ K = 365° C.

For ratio of 5: $\ln 5 = 1.6 = 28.9 - \frac{1.8 \times 10^4}{T}$.

and $T = 658°$ K = 386° C.

At a temperature of 400° C = 673° K the ratio is

$$\frac{N_{400}}{N_{350}} = 8.6$$

That is, if observed at 400° C an organism seen also at 350° C could (presumably) tolerate 8 times the radiation it is receiving between the wavelength 750 nm and 850 nm.

The characteristics of the CCD of ALISS are [S.N. White, private communication]:

Readout noise: 12 electrons per pixel = σ_R

Dark current: 1.2 electrons sec^{-1} $pixel^{-1}$, so noise per pixel from dark current for a time T is $\sqrt{1.2T} = \sigma_D$

Array: 1024 x 1024 pixels, divided into 9 tiles by the optics system

Pixel size: 24 x 24 microns^2 = 5.76 x 10^{-6}cm^2

Frame readout time $\sim$ 2 sec

Demagnification of optics 0.047

Diameter of lens 0.6 cm (lens array 3 x 3)

Quantum efficiency of CCD at 800 nm = 0.65

Focussing distance 50 cm

Solid angle subtended by the complex optics system for each lens 4.5 x 10^{-5} sr.

Attenuation of sea water at 800 nm = $\alpha = 0.03 cm^{-1}$

From these parameters, each cm^2 of source focusses down to 2.2 x 10^{-3} cm^2 on the chip, i.e., onto 383 pixels. The sum of the chip noise from reading out the pixels corresponding to 1cm^2 of source is

$$N_c = \sqrt{383} \cdot \sqrt{\sigma_D^2 + \sigma_R^2} = \sqrt{383}\ \sqrt{1.2T + 144} \tag{4}$$

Now suppose an organism 1cm^2 that has been observed at 400°C is under observation at 350°C at a distance of 10 cm from the vent. The solid angle it subtends from A cm^2 of source is A x 10^{-2}, the attenuation of 800 nm radiation is $e^{-0.3}$. The amount of radiation received by this square centimeter is 1.2 x 10^9 x A x 10^{-2} x 0.74 = 8.9 x 10^6 A photons sec^{-1}. From inspection of records from previous ALISS dives it is reasonable to consider vent light from an area of A = 10 cm^2, so the light received is 8.9 x 10^7 photons sec^{-1}. From the arguments above, consider illuminating the 1 cm^2 organism at 800 $\pm$ 50 nm with 8 times that amount of light, and attempting to view it with ALISS, assuming that one tenth of the illumination is reflected into a solid angle of 2π.[3] The number of electrons provided by this signal would be 8 x 8.9 x 10^7 x 10^{-1} x $(2\pi)^{-1}$ x 4.5 x 10^{-5} x $e^{-1.5}$ x .65, or S = 73 electrons from 383 pixels. For 10 sec integration the signal is 730 electrons and the noise of the signal is $\sqrt{730}$. For the 383 pixels covered by this signal the chip noise for 10 sec is (Eq. 4)

$$N = \sqrt{383} \cdot \sqrt{156} = 244$$

so, including the signal noise, the signal/noise ratio is

$$\frac{S}{N} = 3.0 .$$

For a 20 sec integration

$$\frac{S}{N} = 5.7 .$$

In the proposed application there would be no optical filters used, so additional "natural" ambient vent light would contribute to the signal in the area of interest.

ALVIN pilots have demonstrated the capability of holding steady in the dark for 5 minutes. This suggests the possibility of a time sequence of records showing the recovery of organisms from the effect of ALVIN landing lights, perhaps a return to normal behavior, or response to selected stimuli.

These same calculations could be made for light at 600 ± 50 nm with an advantage of 1.23 in the quantum efficiency of the CCD chip, and a factor of 3.9 from reduced sea water attenuation. Even so, artificial illumination at the longer wavelength might be preferable because of the effect on the organisms, particularly, for example, on the shrimp Rimicaris exoculata.(4

If the electronics of ALISS were to remain the same, but the optics designed to be dedicated to the observations suggested, further gains in signal to noise could be realized:

1. A single lens of 1.2 cm diameter (instead of 0.6 cm) represents an acceptance solid angle gain of a factor of 4.

2. A focal distance of 25 cm (instead of 50 cm) provides a gain of a factor of 4 in solid angle, and a further factor of 2.1 because of sea water attentuation at 800 nm.

References

1. S.N. White, A.D. Chave, G.T. Reynolds, E.J. Gaidos, J.A. Tyson, and C.L. Van Dover, Geophys. Res. Lett. 27, 1151-1154 (2000).

2. S.N. White, Doctoral Dissertation MIT, WHOI, June 2000.

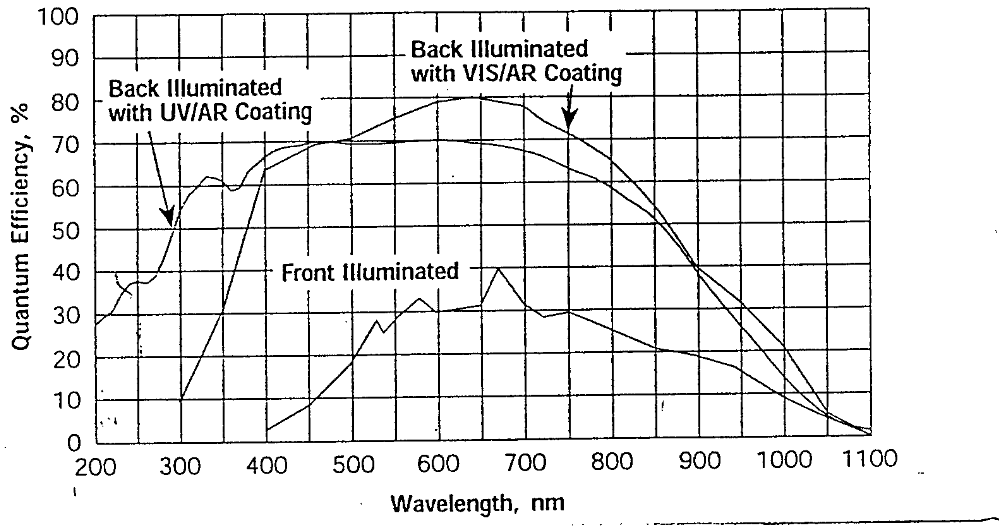
3. This assumption should be checked in the laboratory. It will be a function of the wavelength.

4. C.L. Van Dover, E.Z. Szuts, S.C. Chamberlin, J.R. Cann, Nature 337, 458-460 (1989).

Figures

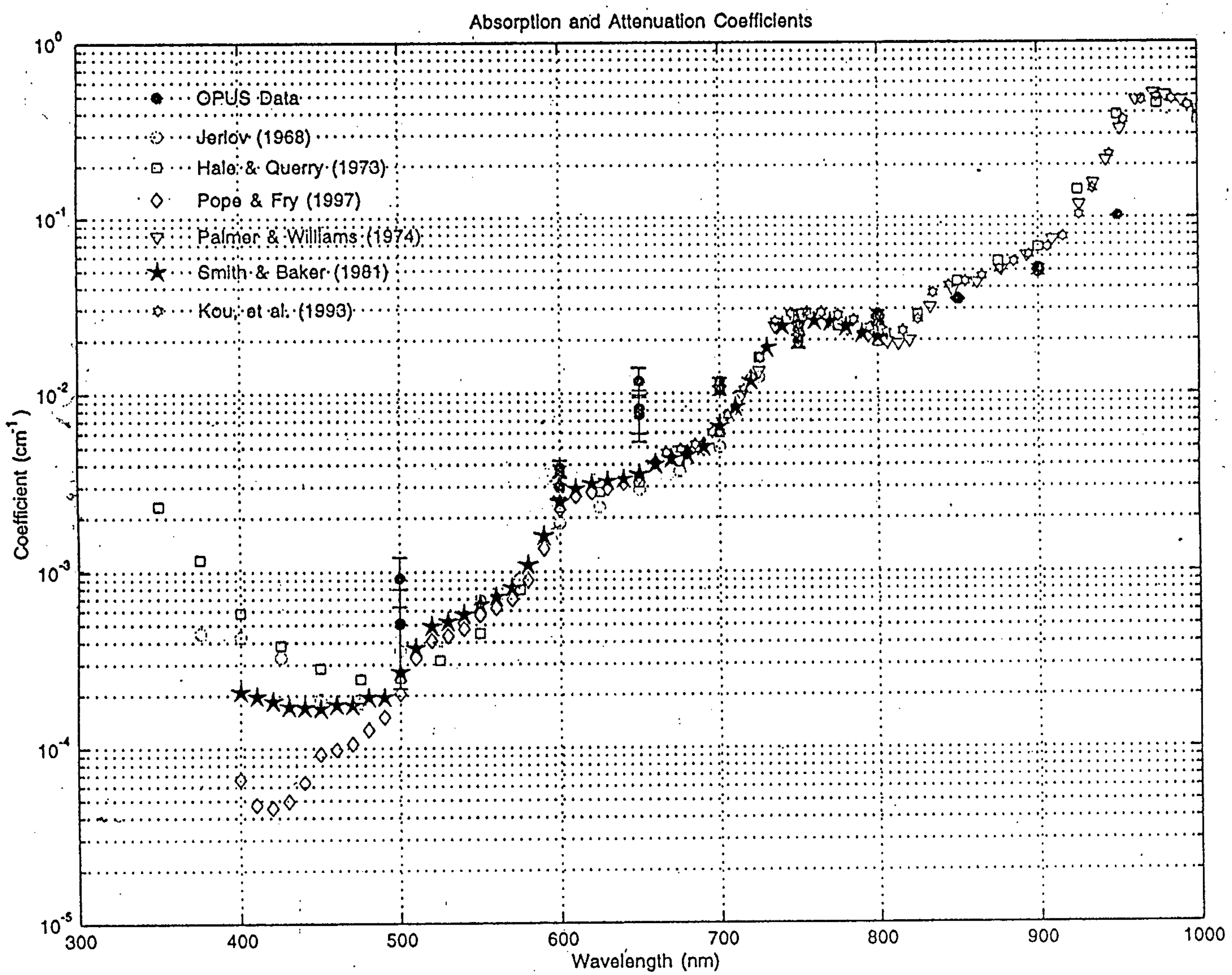
Fig. 1 Quantum efficiency of the CCD Camera used in ALISS.

Fig. 2 Attenuation coefficient of sea water. From S.N. White, reference 2.



100
90
80
70
60
50
40
30
20
10
0
Quantum Efficiency, %
Back Illuminated
with VIS/AR Coating
Back Illuminated
with UV/AR Coating
Front Illuminated
200
300
400
500
600
700
800
900
1000
1100
Wavelength, nm

Figure 1



Absorption and Attenuation Coefficients
OPUS Data
Jerlov (1968)
Hale & Querry (1973)
Pope & Fry (1997)
Palmer & Williams (1974)
Smith & Baker (1981)
Kou, et al. (1993)
Coefficient (cm^{-1})
Wavelength (nm)

FIGURE 2

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14. ABSTRACT
It is likely that the bright lights of a deep sea submersible coming into position at a hydrothermal vent seriously disturbs the behavior of the life found there. It may be of interest to observe the "normal" behavior or natural response to selected stimuli. A possible means of providing illumination that permits such observation is discussed.

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